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# ADP012360

TITLE: The RCM1 - A Test Case. A First Attempt to Model a Supercritical Cryogenic Injection Using the CPS Code

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## This paper is part of the following report:

TITLE: 2nd International Workshop on Rocket Combustion Modeling: Atomization, Combustion and Heat Transfer held in Lampoldshausen, Germany on 25-27 Mar 2001

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ADP012355 thru ADP012373

# The RCM1_A test case

# A first attempt to model a supercritical cryogenic injection using the CPS code

2nd International Workshop on Rocket Combustion Modelling
Lampoldshausen March 25-27, 2001

Presented by Laurent Lequette form Bertin Technologies

1. The introduction
2. The objectives and the approach
3. The main results
4. The numerical and the physical models
5. The results presentation
6. The conclusion

# 2nd RCM Workshop : RCM1_A test case
## The introduction

- Bertin Technologies
  - technological services provider and consultancy
  - French private company
  - staff : 250 employees

- The SIMA team
  - working in Information Systems and Advanced Modelling
  - has been involved in CFD modelling for more than 15 years and has developed several CFD tools like CALIFE, THESEE and now CPS

- This work has been founded by CNES

# 2nd RCM Workshop : RCM1_A test case
## The introduction

The CPS code

- new generation CFD code
  - unstructured meshes (3D)
  - Roe and Toumi formulation for Euler fluxes
  - explicit and implicit schemes (for steady and for unsteady flows)
  - turbulence models (Jones-Launder, Coakley, RNG, subgrid, ...)
  - Eulerian two phases model
  - Lagrangian two phases model (LASVEGAS)
    - atomisation and coalescence
    - arbitrary time step
    - high volumic rates
  - Combustion models ( Arrhenius, TECK, flame surface )

- developed by Bertin Technologies and SNPE Group together
  - benefits from earlier developments of both companies

- a commercial version is being launched
  - we are looking for pilot customers

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## The objectives and the approach

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- The objectives
  - To have a first attempt to use CPS for supercritical flows
  - To retrieve guidelines for future developments of CPS
    - numerical point of view
    - physical models

- The approach
  - Several numerical strategies have been explored
    - two phases flow
    - single phase flow using Roe-Toumi fluxes and real gas law
    - single phase flow using a the ICED-ALE scheme and real gas law
      - implicit pressure treatment
      - transport of internal energy
  - Equation of state
    - large validity range Benedict-Weeb-Rubin (BWR) formulation
    - sound speed derived from this formulation

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## The objectives and the approach

- The BWR equation of state for Nitrogen
  - 33 coefficients

$$P(T,\rho)=\frac{\rho.R.T}{M}+\left(A1.T+A2.\sqrt{T}+A3+\frac{A4}{T}+\frac{A5}{T^2}\right).\rho^2+\left(A6.T+A7+\frac{A8}{T}+\frac{A9}{T^2}\right).\rho^3+$$
$$+\left(A10.T+A11+\frac{A12}{T}\right).\rho^4+A13.\rho^5+\left(\frac{A14}{T}+\frac{A15}{T^2}\right).\rho^6+\frac{A16}{T}.\rho^7+\left(\frac{A17}{T}+\frac{A18}{T^2}\right).\rho^8+$$
$$+\frac{A19}{T^2}.\rho^9+\exp\left(-\gamma.\rho^2\right)\left[\begin{array}{l}\left(\frac{A20}{T^2}+\frac{A21}{T^3}\right).\rho^3+\left(\frac{A22}{T^2}+\frac{A23}{T^4}\right).\rho^5+\left(\frac{A24}{T^2}+\frac{A25}{T^3}\right).\rho^7+\\+\left(\frac{A26}{T^2}+\frac{A27}{T^4}\right).\rho^9+\left(\frac{A28}{T^2}+\frac{A29}{T^3}\right).\rho^{11}+\left(\frac{A30}{T^2}+\frac{A31}{T^3}+\frac{A32}{T^4}\right).\rho^{13}\end{array}\right]$$

- The BWR enthalpy for Nitrogen

$$H(p,T)=H_0+\int_{T_0}^{T}C_{p,0}(T)dT+\frac{p}{\rho(p,T)}-\frac{R.T}{M}+\int_0^{\rho(p,T)}\left(\frac{p}{\rho^2}+\frac{T}{\rho^2}\left(\frac{\partial p(\rho,T)}{\partial T}\right)_\rho\right)_T d\rho$$

avec $H_0 = 0$

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## The main results

- The two phases approach could be interesting but is not mature enough in CPS for such a case
- As it is the Roe-Toumi scheme doesn't allow to use real gas properties
  - simplified laws may allow easier derivation
- The "old" ICED-ALE scheme works well for this case, without noticeable numerical difficulty, but :
  - the current API for real gas equation doesn't cover all aspects and has to be extended
  - the polynomial approach for Cp and Cv has to be extended to be more flexible
  - simplified boundary conditions had to be used in order to avoid perfect gas formulation
- For multispecies application the state of law for the mixing has to be built

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## The numerical and the physical models

- Numerical models and parameters
  - Second order ICED-ALE scheme with implicit pressure treatment
  - CFL 5
  - conjugate gradient with ILU preconditioning
  - unsteady

- Physical models and parameters
  - BWR law of state
  - constant Cp and Cv      $Cp = 1200.\ J.kg^{-1}.K^{-1}$      $Cv = 800.\ J.kg^{-1}.K^{-1}$
  - constant laminar viscosity
  - Jones-Launder $(k,\varepsilon)$ turbulence model

- Mesh
  - 3230 elements
  - 154 elements in the axial direction

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## The numerical and the physical models

- Inlet boundary conditions : fixed values
    - Ps = 39.7 $10^5$ Pa    Ts = 126.9 K    v = 0.769 m $s^{-1}$
    - k = 0.0024 $m^2.s^{-2}$    $\omega$ = 10. $s^{-1}$
- Outlet boundary conditions : fixed pressure
    - Ps = 39.7 $10^5$ Pa    Ts = 293. K (for reentrant flow only)    Free velocity
    - k = 0.1 $m^2.s^{-2}$    $\omega$ = 40. $s^{-1}$
- Injector and pipe wall conditions
    - Adiabatic    slip condition with friction
- Chamber back wall
    - Adiabatic    Ordinary law of the wall
- Chamber lateral wall
    - Fixed temperature Tw = 297 K    Ordinary law of the wall
- Initial conditions
    - downstream values with zero velocity

## 2nd RCM Workshop : RCM1_A test case
## The results

- The results correspond to
  - 50 000 time steps with laminar first order scheme
  - then 100 000 time steps with turbulent second order scheme
  - total CPU time 26 h on a Linux Xeon 350 MHz

- The results are converged in the jet spreading
  - at least down to 80 mm after injector outlet

- All the presented results are drawn with a radial to axial scale ratio of 5

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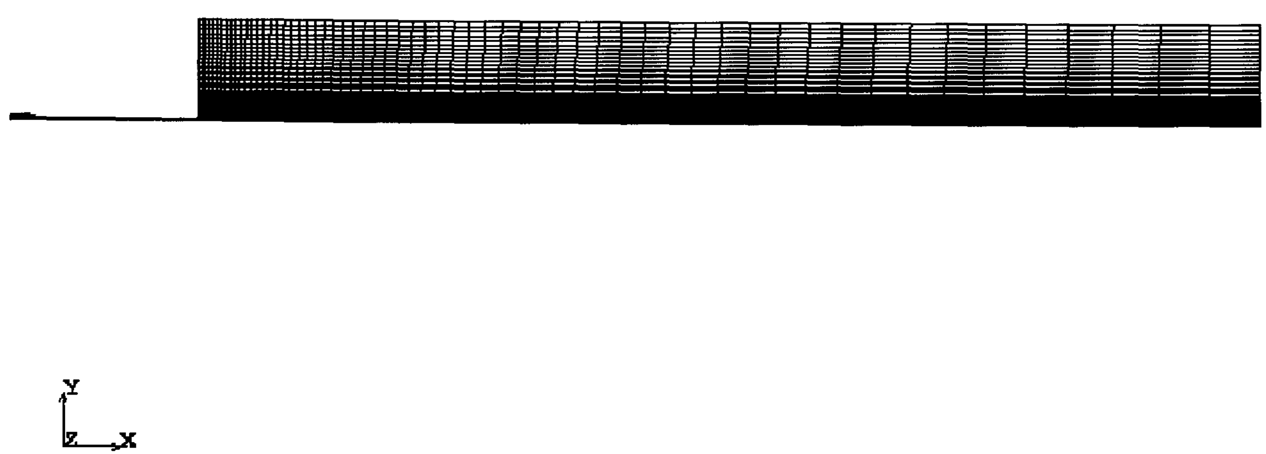
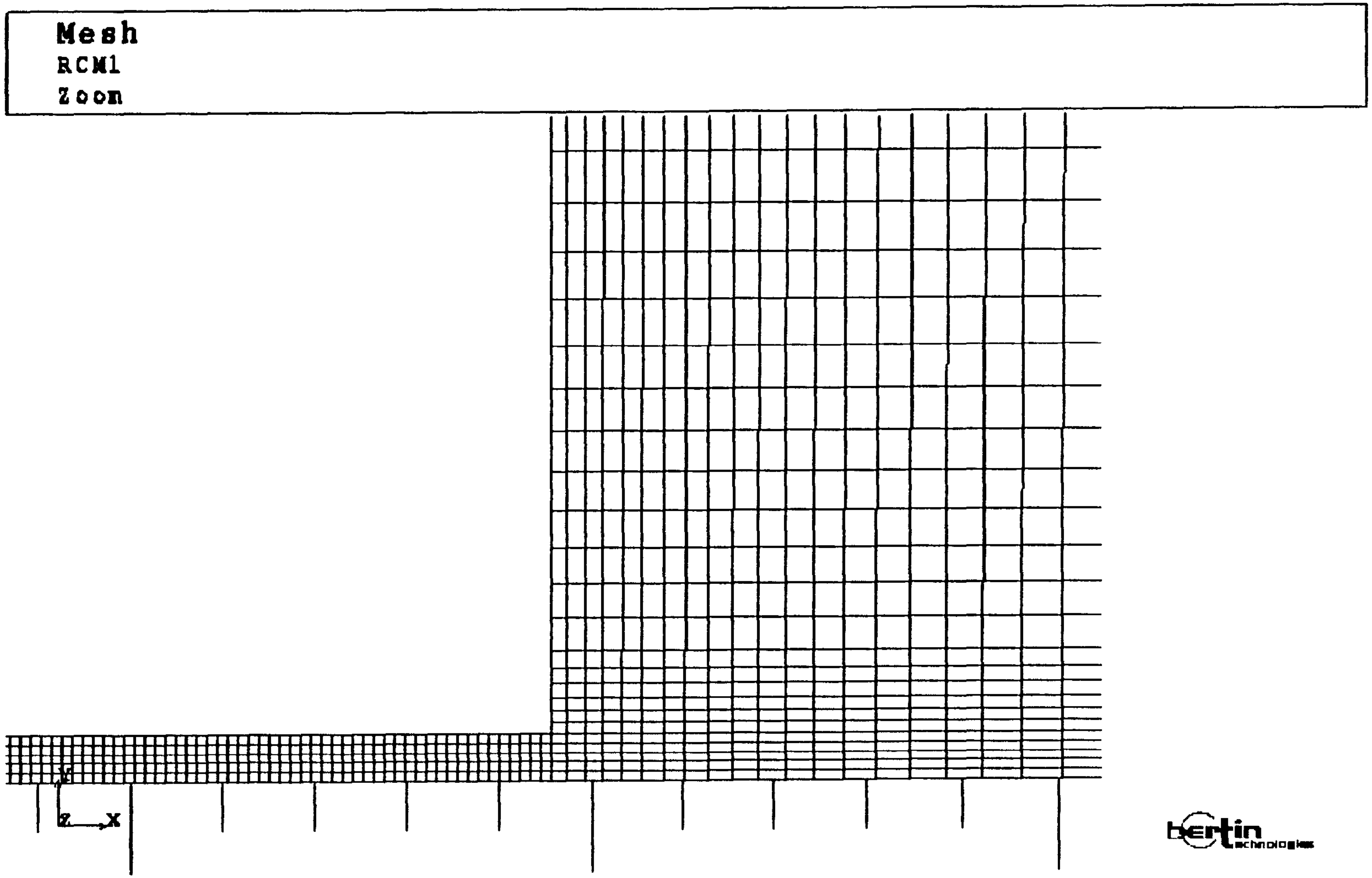
## The results

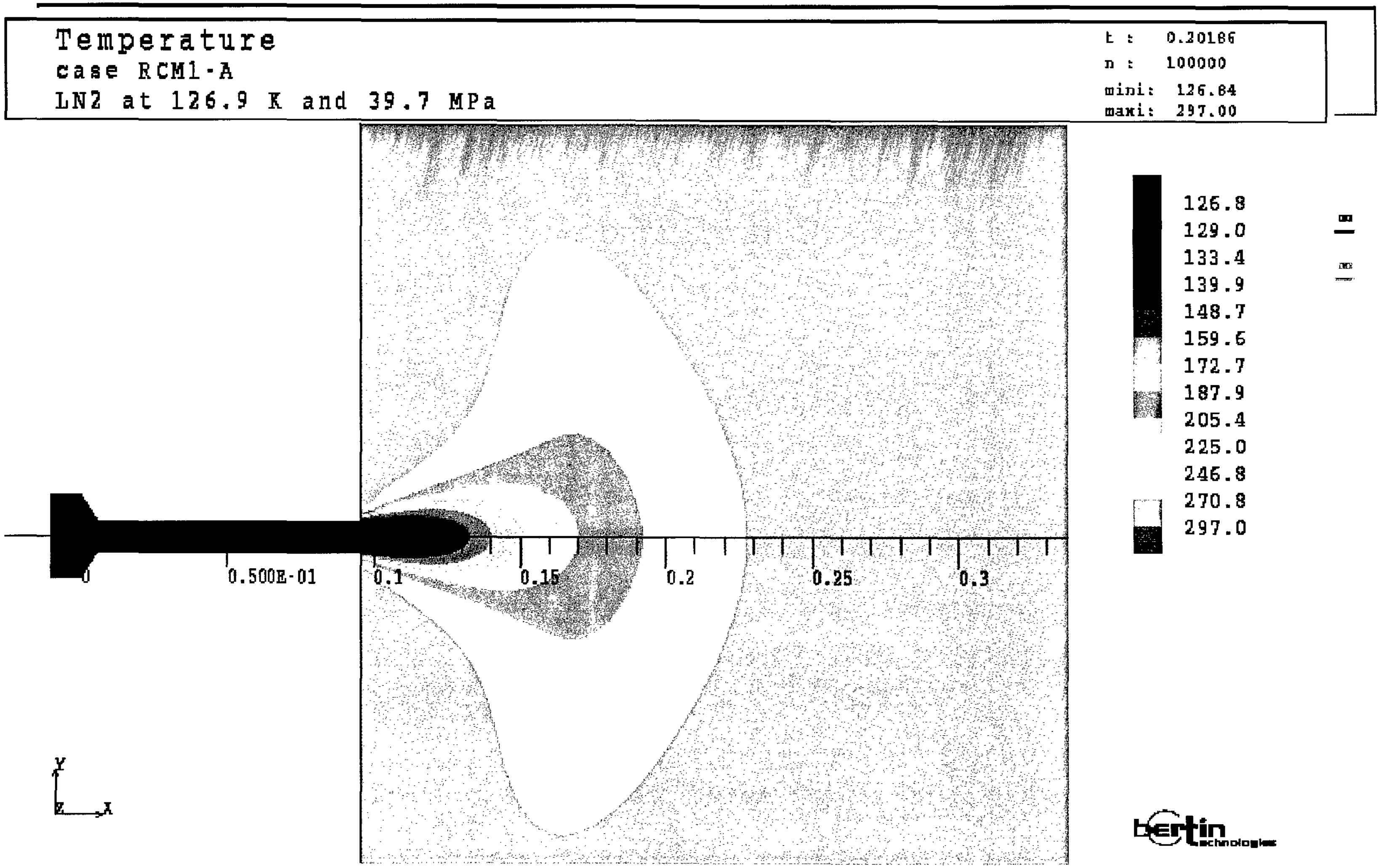
**Mesh**
RCM1
Overall view



# 2nd RCM Workshop : RCM1_A test case
## The results



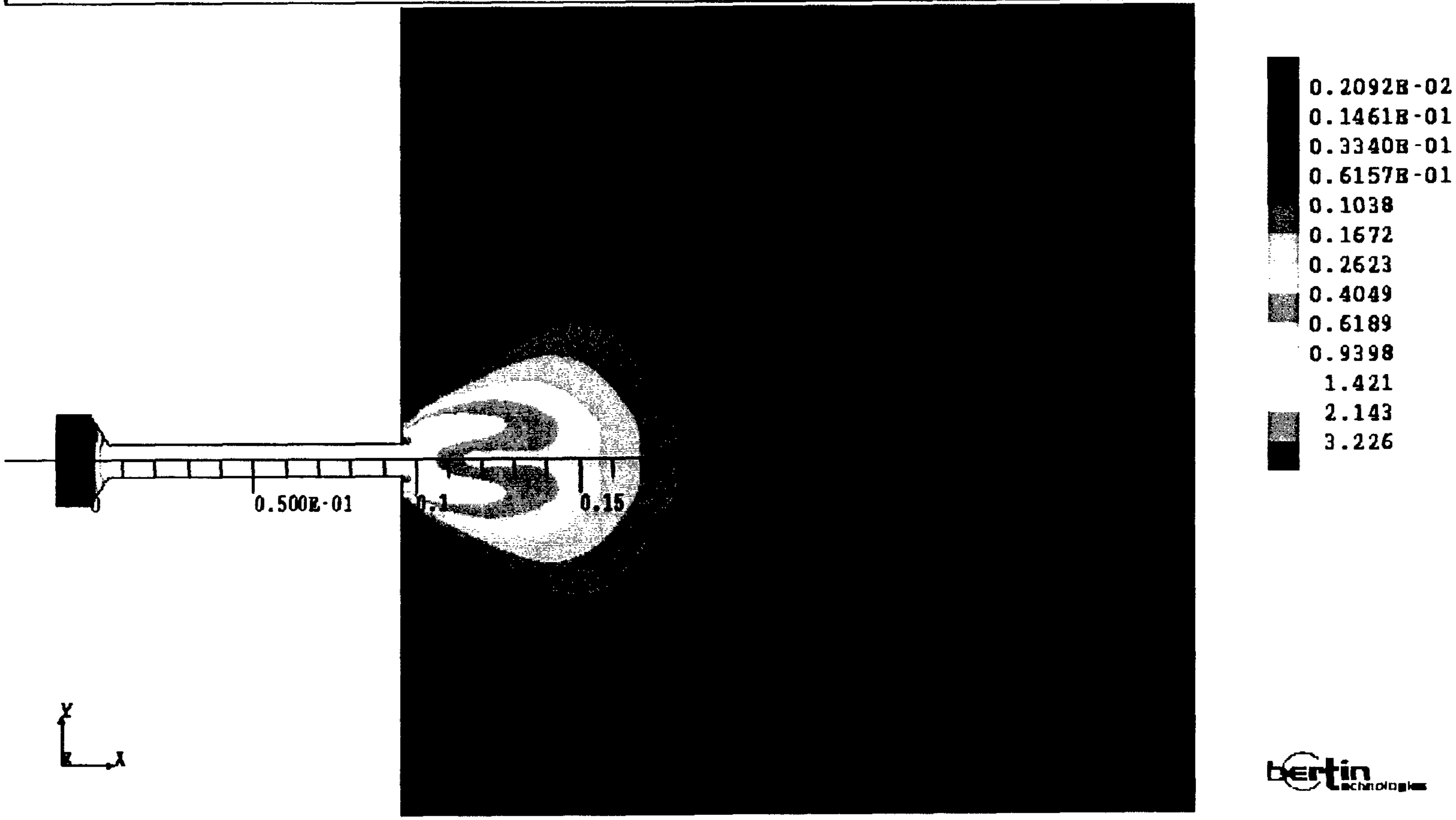
# 2nd RCM Workshop : RCM1_A test case
## The results



# 2nd RCM Workshop : RCM1_A test case
## The results

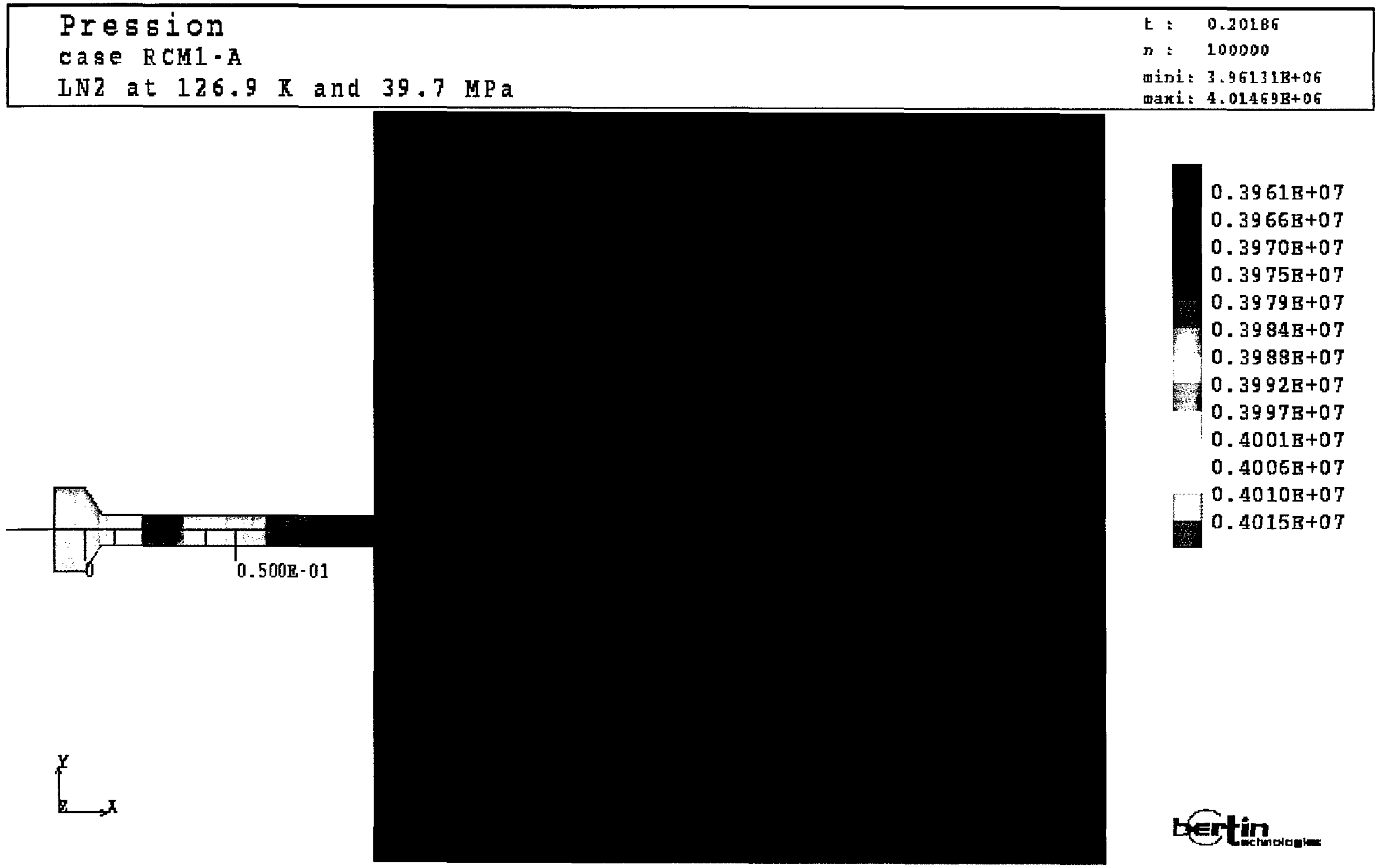
Energie cinetique turbulente
case RCM1-A
LN2 at 126.9 K and 39.7 MPa

t : 0.20186
n : 100000
mini: 2.09170E-03
maxi: 4.8508

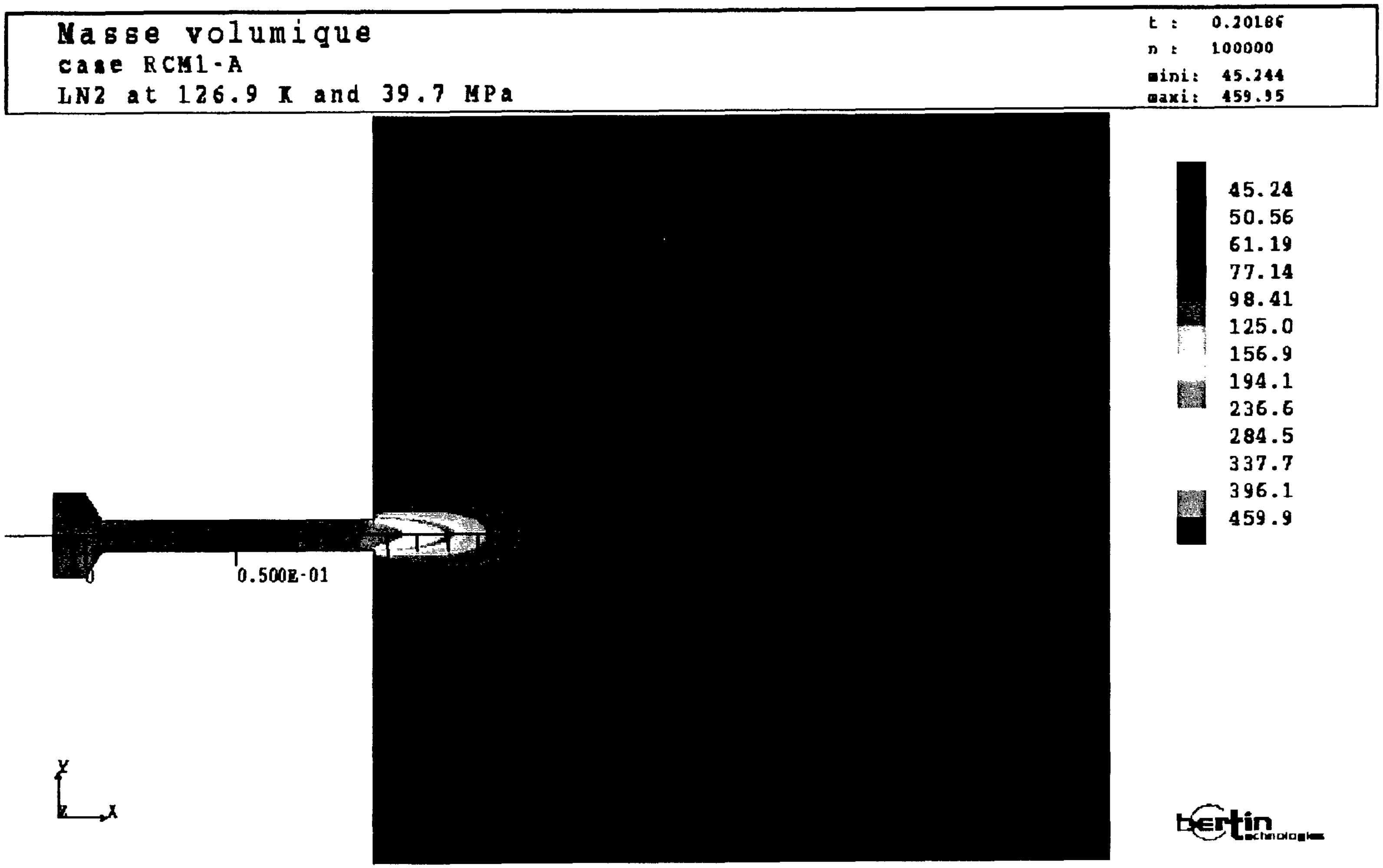


# 2nd RCM Workshop : RCM1_A test case
## The results

5

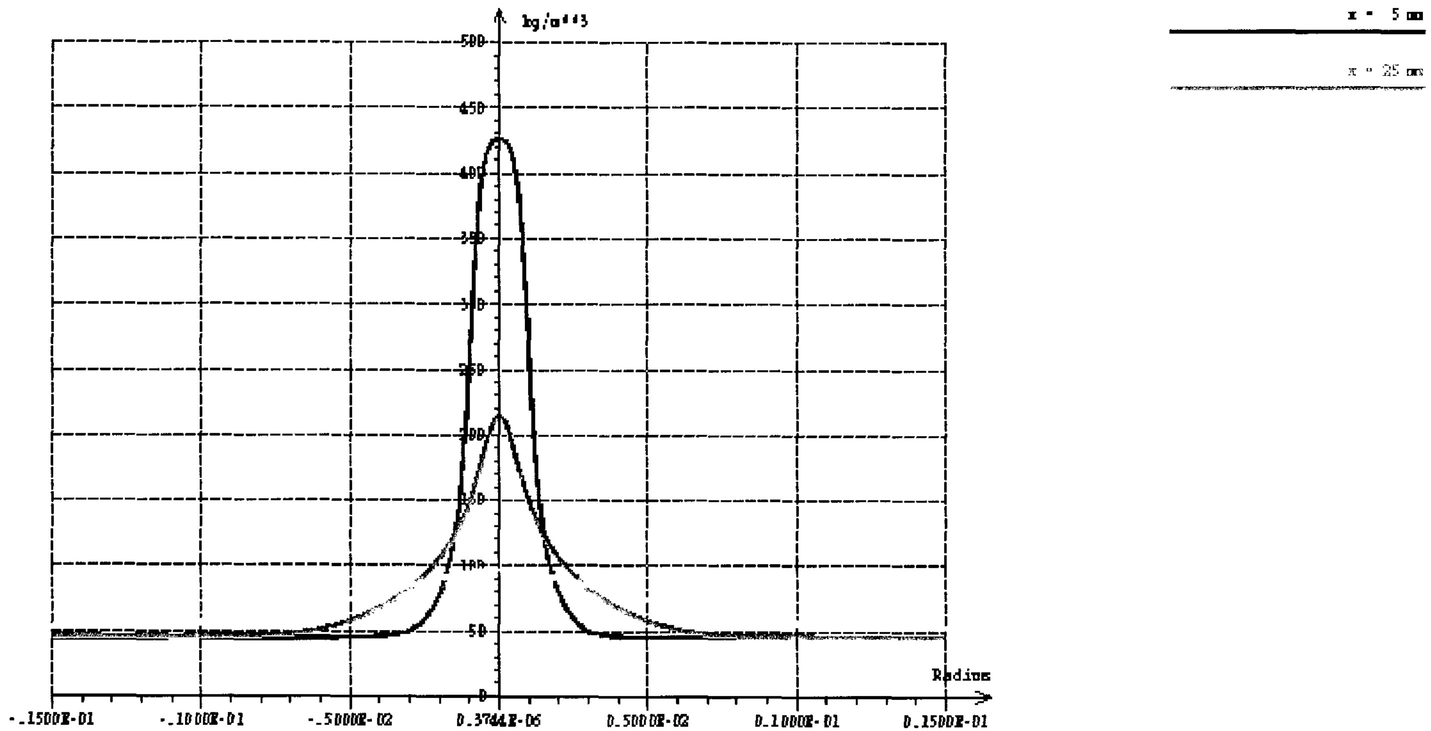


# 2nd RCM Workshop : RCM1_A test case
## The results



# 2nd RCM Workshop : RCM1_A test case
## The results

| | |
|---|---|
| Masse volumique | t : 0.20186 |
| case RCM1-A | n : 100000 |
| LN2 at 126.9 K and 39.7 MPa | mini: 45.244 |
| | maxi: 459.95 |



## 2nd RCM Workshop : RCM1_A test case
## The conclusion

- This preliminary attempt to model a supercritical cryogenic injection with a general purpose code has shown that it is feasible

- Sophisticated thermodynamic laws :
  - can be taken into account with simple numerical schemes
  - require to adapt many features including boundary conditions
  - cannot yet be taken into account easily for ordinary users
  - induce a large CPU cost

- Further developments must be done to be able to use Roe-Toumi fluxes

- Simplified laws would help to implicit these schemes